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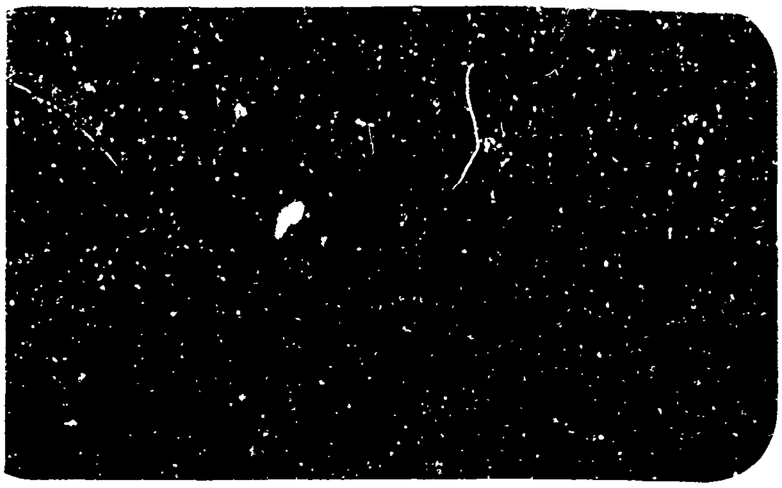

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Vapor-Space-Corrosion Inhibited Oils for Use in Steam-Turbine Lubricating Systems

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ABSTRACT

Incorporating vapor-space-corrosion inhibitors in operating steam-turbine oils has been shown by laboratory experiments to be feasible. Two oils appear suitable for use in steam-turbine lubricating systems. Further confirmatory testing of side effects is underway.

ADMINISTRATIVE INFORMATION

This is a phase of the investigation which was authorized by reference (a) and is included in Sub-project S-F020 03 05 (formerly S-R001 07 01), Task 0601.

REFERENCE

(a) BUSHIPS ltr R001 07 01 ser 634A-296 of 2 Jul 1962

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VAPOR-SPACE-CORROSION INHIBITED OILS FOR USE IN STEAM-TURBINE LUBRICATING SYSTEMS

1.0 INTRODUCTION

Severe problems of corrosion in steam-turbine lubricating-oil systems have been reported by the Navy's Bureau of Ships, its Board of Inspection and Survey, and by ships' operating personnel. These problems have been concerned almost entirely with the steel surfaces bounding spaces not normally submerged in the oil. These spaces are known as vapor spaces because of the presence of water and oil vapors in the air contained in them. An example of the severity of the rusting can be seen in Figure 1.

The corrosion product, rust, when broken loose from the steel surfaces and circulated through the oil system, can be expected to cause many performance problems, such as reduction gear scoring, bearing wear, and sluggish hydraulic governor operation. In addition, the rust may contribute to an increased consumption of oil additives and to increased sludge formation.

The concept of using vapor-space-corrosion inhibitors (VSI) in the oil appeared to offer the best solution to corrosion control in all the vapor spaces of the system. Such inhibitors have been known for approximately 20 years, but their major application has been in packaging for the protection of equipment or parts in storage or shipment rather than for the protection of operating machinery. Recent work[1,2] was pointed toward the use of VSI materials in steam-turbine lubricating-oil systems. One oil s supplier is evaluating a VSI turbine oil in a main propulsion turbine of a commercial tanker. The results of an investigation of the feasibility of this approach as a solution to the U. S. Navy's problem are reported here, as a phase of the MEL program to develop a vapor-space-corrosion inhibited turbine lubricating oil.

2.0 METHOD OF ATTACK

2.1 <u>Definition of the Problem</u>. Large quantities of air are introduced into steam-turbine lubricating oils through the bearings and the gear cases. Varying amounts of moisture enter the system

[1]Superscripts refer to simil rly numbered entries in Appendix B.

with the air, and water also enters from turbine gland or oil-cooler leaks. Therefore, two prominent contributors to metallic corrosion (air and water) are usually present. In addition, varying concentrations of salt particles which can act as corrosion-sponsoring nuclei also may be present. The corrosion inhibitors normally used in turbine oils reliably protect only the surfaces continuously wetted with oil; thus, corrosion generally can be expected to occur in the spaces not so wetted. Vapor spaces are present in bearing pedestals, oil-return lines, sumps, and gear cases. The air in these spaces contains water vapor, from the relative humidity of the air entering the system and from evaporation of water entrained in the oil. Causes of water in the oil include system temperature fluctuations, turbine gland seal condition, oil-cooler leaks, the frequency and quality of operation of the oil purification system, and certain system design features. Vapor-space-corrosion inhibitors, which would protect all affected areas and which could be included in the turbine oil, offer a promising approach for combating this difficulty.

2.2 Requirements of VSI Materials for Operating Oil Systems. Many requirements of VSI materials in steam-turbine lubricating-oil systems may be listed. The VSI material not only should have a vapor pressure to give an effective concentration in the vapor spaces at system operating temperatures (140-160F),* but also should have sufficient vapor pressure to provide adequate protection during short periods of system shutdown (low temperature). At the same time, the vapor pressure should not be so high as to cause early loss of active material. Once in the vapor spaces, the VSI material must diffuse to the metal surfaces and protect them. In addition to the corrosion prevention requirements, VSI material must be compatible with other steam-turbine oil additives (i.e., oxidation inhibitors, liquid-phase rust inhibitors, and load-carrying additives). Furthermore, the material must be compatible with the nonferrous materials found in steam-turbine lubricating-oil systems. Thus, the VSI turbine oil not only must afford vapor-space protection but also must meet the major requirements of the military specification (MIL-L-17331) for steam-turbine lubricating oils.

*Abbreviations used in this text are from the GPO Style Manual, 1959, unless otherwise noted.

2.3 Materials Investigated. Because the protection of steam turbine lubricating-oil systems is of commercial as well as Navy interest, two oil companies have conducted some development work on VSI oils. One has progressed in development to the stage of full-scale evaluation on a ship of its tanker Fleet. The Laboratory obtained for evaluation two oil formulations from each of these two manufacturers. These are coded A, B, C, and D in this report.

In addition, three VSI oils were prepared in the Laboratory by blending into a standard Navy turbine oil (Code H) three different vapor-space inhibitors which had been reported to be effective. These oils were coded E, F, and G. Experiments were conducted on these seven oils, as well as on Oil H, which was used to represent current performance of Navy turbine lubricating oils.

2.4 Experimental Approach. The basic experimental approach was the evaluation of the available materials under conditions simulating the environment of the oil system, with respect to rust protection, additive depletion rate, and compatibility with materials of the system. The effects of VSI additives on other important performance properties of the oils were also measured. For the environmental evaluation of the oils, an apparatus was designed which combines many of the environmental features of a steam-turbine lubricating system. This apparatus, shown in Figure 2, incorporates many of the practices used for designing steam-turbine lubricating systems as recommended by ASTM and ASME[3] with respect to vapor-space corrosion problems in the sump, gear case, and bearing-oil-return lines. With a normal Navy turbine oil (Code H) in the apparatus, operating conditions were selected to simulate both shipboard turbine operation and vapor-space corrosion experience. The effectiveness of the vapor-space corrosion inhibited oils was determined under these selected conditions. Those oils showing effective vapor-space corrosion inhibition were then examined for their conformance to the essential requirements of Military Specification MIL-L-17331 and subjected to other studies to illuminate the behavior of vapor-space inhibited oils.

3.0 DETAILS OF ENVIRONMENTAL TEST APPARATUS

The environmental test apparatus, Figure 2, consists of an oil circulating system containing an oil sump, a pump, an oil heater, a gear-case spray nozzle, and a bearing return line. Means of adding humidified air at controlled rates are provided. Evaluation of performance is based on rusting of exposed surfaces of the sump and oil-return line, as well as of various specimens and

electrical-resistance type corrosion probes installed in the sump.

3.1 Oil Sump. Mild steels similar to those used in ship construction were used in the sump construction. It was designed for an oil capacity of 4 gallons. This provides a distance from the oil surface to the overhead of approximately 1 foot, which allows about one-quarter of the sump volume as vapor space, a common sump design practice. As shown in Figure 2, the pump suction line is positioned above the sump bottom which is sloped downward from the pump suction toward the opposite end of the sump. This arrangement is intended to prevent the circulation of large amounts of free water. In addition, the suction line is remotely located with respect to the return line so that all the oil is circulated with minimum recontaminantion from materials settled in the sump. On entering the sump from the oil-return line, the oil flows across a baffle which facilitates the release of air picked up in other parts of the system. The excess air escapes through a vent located directly above the baffle. A cooling coil is mounted outside the sump on a wall to ensure condensation on the inside wall when desired. This device is not needed to cause condensation on the sump cover under the conditions used in these tests. Not shown in Figure 2 is a sump wall extension which increases the height of the sump cover above the oil level from 1 foot to 6 1/2 feet. This extension may be used to show that VSI materials will provide protection in remote regions of the vapor spaces, such as gear covers. Liquid and vapor temperatures as well as the vapor relative humidity are measured in the sump.

3.2 Pump and Flow Control. As shown in Figure 2, the oil is circulated by a positive displacement pump with a bypass valve. The bypass valve is set before the run to produce the desired flowrate in the oil system. Flowrate is measured by collecting the oil pumped, at operating temperature and pressure, in a calibrated container. No adjustment of the bypass valve is normally made during a run. Operating pressure and the level in the return line sight gages are used to monitor the oil flowrate throughout the test. The oil is pumped from the sump through a heater with automatic temperature control. The 600-watt electric heater is sized to provide a low heat-flux density. This low flux density, together with the automatic temperature control and the low-oil-flow shutdown device, ensure against high local oil temperatures. (After approximately a year of service, there was no carbonaceous material adhering to the heating element material).

3.3 Bearing-Oil-Return Line. Following passage through the heater, the oil flow is divided. Approximately 97 percent of the oil flows through a hand valve and into the bearing-oil-return line, which consists of a replaceable 2-foot length of 3/4-inch pipe situated between two sight glasses. The return line is sized to run half-full with an oil flow of approximately 0.8 gpm (one-fifth of sump oil capacity as recommended).[3] This return line is sloped approximately 2 inches per foot toward the sump, a figure somewhat in excess of the 1/2 inch per foot minimum recommended by the ASTM-ASME design practices.

3.4 Gear Case. The remaining 3 percent of the oil flows to the simulated gear case. This gear case mock-up contains no gears but is provided with an oil spray nozzle to simulate oil spraying in the gear case. The pressure to the nozzle (pump discharge pressure) is regulated by the oil-return-control valve shown in Figure 2. In addition, a jet supplies hot air in contact with the oil droplets, with both the temperature and flow of air controlled. A predetermined amount of oil is blown out the vent by varying the air flow, and this oil is collected in a graduated cylinder. An oil seal is provided by use of a valve at the gear-case drain. Both the oil and vapor temperatures are recorded.

3.5 Humidifying Equipment. Leakage of air, steam, and condensate into the lubricating oil is simulated by use of air saturated with water at elevated temperatures. The use of saturated air not only supplies the air-water environment present in operating turbines but also allows precise control of the amount of water entering the system. As shown in Figure 2, air is bubbled through a water layer in a temperature-controlled, air-humidifier chamber. The saturated air leaving the chamber, heated by line heaters slightly above its dew point, passes through a flowmeter into the pump suction. The air temperature at the pump suction is controlled to match the air temperature in the chamber; thus, saturation is assured.

3.6 Measurement of Corrosion Inhibition. The chief assessment of corrosion-inhibition effectiveness is made by examining the sump area of the apparatus. Corrosion in the sump area is measured by three methods. First, removable mild steel liners are bolted to the sump cover and walls in the vapor space. These liners are polished with 100 grit aluminum oxide cloth and washed with naphtha and then isopropyl alcohol to provide a similar starting point for each corrosion test. Ports are provided for viewing the progress of corrosion on these liners. Second, a rack is provided for

holding various corrosion test coupons in both the vapor and liquid phases. Third, in addition to the above, replaceable electrical-resistance-type corrosion probes are used in both the liquid and vapor phases.

Experience with the apparatus showed that, as the length of operation was increased beyond 1000 hours, significant corrosion-inhibition evaluations could be obtained by longitudinally sectioning the replaceable oil-return line at the liquid-air interface and examining the portion not wetted by the oil under test.

4.0 DEVELOPMENT OF A TEST METHOD

As a base line step, the apparatus was run with the MIL-L-17331 specification lubricating oils, MS 2190-TEP, to determine the atmospheric conditions in the sump necessary to produce vapor-space corrosion similar to that experienced in service.

4.1 Noncondensing Atmosphere. In several runs, test conditions were set so that no condensation occurred. This type of operation limited the measured relative humidity in the sump to 60 percent (measured 1/2 to 1 1/2 inches from sump wall). After 21 days under these conditions, no corrosion was observed either on the vapor-space surfaces of the apparatus or on mild steel test coupons and the resistance-type corrosion probes. These results agree with those reported by Vernon,[4] in which the corrosion rate was insignificant below approximately 75 percent relative humidity (RH).

4.2 Condensing Atmospheres. A condensing atmosphere approach was undertaken to increase the severity of the vapor-space corrosion and to decrease the test time required. Operation of the apparatus with a MS 2190-TEP oil (Code H) and a condensing atmosphere (100% RH) in the sump and oil-return line resulted in severe corrosion of the vapor-space surfaces of the sump after 45 hours of operation. The first traces of condensate were observed on the underside of the sump overhead approximately 2 hours after the introduction of saturated air to the system. Approximately 2 hours after condensate was observed, these droplets turned black in color, indicating a beginning of the corrosion process. They grew eventually to approximately 1/4 to 3/8 inch in diameter. Figure 3 shows a sump overhead liner after 45 hours of operation. Both black and red oxides of iron were present. As the condensing atmosphere operation produced severe vapor-space corrosion in short test periods with the MS 2190-TEP steam turbine oil, this type of operation was selected for further work.

4.3 Selection of "Standard" Operation Conditions. As discussed above, test conditions were to be selected so that they would both simulate steam-turbine operating conditions and provide vapor-space corrosion similar to that shown in shipboard operation. For a liquid sump capacity of 4 gallons, the oil flowrate was fixed at 0.8 gpm in accordance with the ASTM-ASME recommended practices.[3] Both the oil temperature and pump discharge pressure of 160 F and 60 psi were selected as representative of shipboard operation. The gear case vapor temperature was arbitrarily set at 180F, as no representative temperatures were available and "severe" conditions were considered essential. The amount of water and air introduced and the test duration were varied to provide vapor-space corrosion similar to that found in shipboard experience. The air flowrates ranged from 200 to 600 ml per minute, and the air was saturated with water vapor at temperatures of 180 to 200 F. These air rates gave corresponding water rates from 3.8 to 17.3 grams per hour. Figure 4 shows the sump cover after 150 hours of operation during which 200 ml per minute of air saturated at 190 F were introduced. Figure 4 compares more favorably with shipboard experience (Figure 1) than Figure 3. The "black" areas in Figure 4 are the remains of blisters which broke when the sump cover was removed. However, before the cover was removed, its appearance was similar to that shown in Figure 1. Thus, the following conditions were adopted as standard for operation of the vapor-space-corrosion apparatus:

Oil quantity	4 gal
Oil flow	0.8 gpm
Oil temperature	160 F
Pump discharge pressure	60 psig
Air saturation temperature	190 F
Saturated air rate	200 ml per min
Gear case vapor temperature	180 F
Gear case vent flow	1 cu ft per min (70 F)

5.0 EXPERIMENTS WITH VSI OILS AND COMMENTARY ON RESULTS

The results obtained on the various VSI oils are discussed below.

5.1 Screening Tests. Seven turbine oils were tested in the apparatus under the standardized operating conditions for 150 hours. The condition of the sump cover liner, and in some cases of the side liner, for Oils A, B, C, and D are shown in Figures 5, 6, 7, and 8. Results similar to those of Oil A were obtained with Oils

E and F, for which figures are not shown. Oil G produced the sump cover condition shown in Figure 9. A comparison of the above with conditions in Figure 4 (MS 2190-TEP, Code H) and Figure 10 (new liner) shows that the commercially supplied oils (B and C) and in-house formulated oil (G) gave only partial protection. Consequently, they were dropped from further consideration.

5.1.1 Commercial VSI Blends. Oils A and D represent commercial VSI turbine oils which gave complete vapor-space-corrosion protection in the screening test. These oils were blended by one manufacturer, but reportedly contained different liquid-phase rust inhibitors. Oil D represents this manufacturer's current MIL-L-17331, MS 2190-TEP formulation with the addition of the VSI material. At the conclusion of the first test of Oils A and D, a green-brown greaselike "scum" was deposited on the sump wall liners at the oil-vapor interface. This material also appeared in the gear-case nozzle strainer, but did not plug the nozzle. In a second test of these oils, like results were obtained. Figure 8 shows both the clean liner surfaces and the interface scum for Oil D. During the latter tests, the formation of scum was observed between the 8th and 32nd hour of operation. During this period, irregular-shaped particles, about 1 to 2 mm in diameter, suddenly appeared on the oil surface, migrated randomly, and finally attached to the sump walls. Also noted in the screening tests of Oils A and D was a white crystalline deposite on both the sump side liner bolts and solder wire used to mount corrosion specimens. This material was identified as heavy metal compounds of the vapor-space rust inhibitor.

5.1.2 Commercial VSI Additives. Oils E, F, and G are combinations of commercially available VSI additives and MS 2190-TEP (Code H) lubricating oil blended at this Laboratory. The VSI material in Oil E is of the amine-salt type, while those in Oils F and G are of the acid type. Oils E and F gave complete vapor-space rust protection in the screening test. The appearance of the sump cover was similar to that shown in Figure 5 for Oil A. The minimum effective concentration in the MS 2190-TEP oil for both inhibitors (no corrosion in 150 hours) was established between 0.05 and 0.1 percent by weight. No adverse effect was found for 150 hours of operation with a blend of 0.1 percent each of the inhibitors in Oils E and F.

5.2 Vapor Pressure Effect. Oil G, also blended at this Laboratory, contained an acid-type VSI material similar to that in Oil F, but with two additional carbon atoms in the straight carbon chain. This increase in carbon-chain length resulted in a decrease of vapor pressure, as compared to Oil F, by approximately one order of magnitude (0.05 versus 0.0065 mm of mercury at 70 C). As shown in Figure 9, only partial protection during the 150 hours of operation was obtained. These results indicate a lower vapor pressure limit for the acid-type inhibitors in this apparatus.

5.3 Volatility. The concentration of VSI materials in the vapor spaces is dependent on their vapor pressure, and hence, on the temperature of the system. As periods of low temperature would be encountered during steam-turbine shutdowns, VSI materials must have appropriate volatility and film tenacity to give protection during these periods. The apparatus with the extended sump was operated with shutdown periods to examine the effect of short periods of low temperature on vapor-space corrosion. These tests were run with the standardized operating conditions varied in the system as follows: on 16 hours (160 F), off 56 hours (90 F), on 16 hours (160 F), and finally off 72 hours (90 F). Thus, the total test time was 160 hours. Oils D, E, and F gave complete vapor-space protection in these tests. Additional tests with Oils D and E were run with the apparatus on 16 hours and off 334 hours. As shown in Figure 11, corrosion of the sump cover began at 350 hours with Oil D, while Oil E gave complete protection for a like period. Hence, both Oils D and E offer some protection at ambient temperatures as well as system operating temperatures. Having demonstrated that VSI materials can offer this protection at ambient temperatures, further testing of Oil F was deferred to permit the use of the apparatus for other needed demonstrations of VSI materials.

5.4 Diffusivity. There was some doubt that these promising VSI materials would protect surfaces at distances greater than those used in the screening tests (approximately 1 foot). Thus, the sump walls were extended so that the distance from the sump cover to the oil surface was increased to approximately 6 1/2 feet. With this modification, one trial each of Oils D and E gave complete vapor-space-corrosion protection for 150 hours. This and subsequent trials of Oils D and E in Section 5.6 below indicate that there should be no problem of diffusion of these inhibitors in the range of distances examined.

5.5 Corrosion Retardation. A desirable factor in vapor-space-corrosion protection is the ability of the inhibitor to retard further corrosion of partially corroded surfaces. To simulate this condition, the 150-hour screening tests were run with partially rusted sump liners. Figure 12 shows the initial condition of the partially rusted liners. As shown in Figures 13 and 14, Oils D and E did not completely retard the spreading of the initial rust spots. However, the corrosion rate was significantly suppressed when compared with MS 2190-TEP oil (Figure 4).

5.6 VSI Depletion and System Compatibility. Studies of inhibitor life in the most promising oils, D and E, were made with the "extended sump" using the standard operating conditions but with continuous operation until vapor-space corrosion was observed. All the oil recovered from the gear-case vent was returned to the system. No makeup oil was added. Also, the condensate (water) layer in the sump was removed at intervals of 150 hours. As these test periods were long with respect to the 150-hour screening tests, system compatibility data became more significant and are presented below with the inhibitor-life test results.

5.6.1 Oil D. The sump vapor-space surfaces were completely protected by Oil D for approximately 1800 hours of operation. Figure 15 shows the beginning of vapor-space corrosion at 1800 hours. However, during this period, several adverse conditions were observed. Severe sludge formation was noted after approximately 300 hours of operation. At this time the gear-case spray nozzle became plugged. The stainless steel screen (90 mesh) protecting this nozzel was completely coated with a green-brown material which gave the appearance of a "filter cake". This material was removed periodically since the condition reoccurred at intervals of 100 to 200 hours throughout the remaining test period. At the conclusion of 1800 hours of operation the sump was drained of oil and inspected. As shown in Figure 16, a large semisolid mass of green-brown material was found on the sump bottom. Visually, this material appeared identical to the scum noted in the screening tests and to the material plugging the nozzle strainer in this test, as well as to the sludge formed in the specification oxidation test (see Section 5.7). In this situation, therefore, there appears to be some correlation between the two tests from an oxidation standpoint.

5.6.1.1 Sludge Analysis. An analysis of the material found on the sump bottom indicated the sludge is composed primarily of turbine oil. Infrared analysis of portions extracted by selective solvents indicated carbonyl functional groups. These could come either from the oxidation of the turbine oil or possibly from the

additive package. Spectrographic analysis of the portion insoluble in hydrochloric acid indicated the major constituents of this portion to be copper, iron, and zinc. The turbine oil supplier's analysis of this sludge indicated also that 0.9 percent sulfur and 2 percent ash were present in this sludge. The copper, iron, and zinc in the sludge can be explained as products of corrosion of the materials of construction used in the vapor-space-corrosion apparatus. The supplier concluded from his analysis that the rust inhibitors were not components of the sludge and that the antiwear additive may have contributed to the sludge formation.

5.6.1.2 Compatibility with Nonferrous Metals. Corrosion of copper in the vapor space also was noted. This was evidenced by a dark color on the copper specimen which felt slippery to the touch. The copper specimen in the oil phase was bright at 1000 hours of operation but had a slight green tarnish at the conclusion of the test (1800 hours). Resistance-type corrosion probes were used to measure the corrosion to aluminum bronze in the the vapor phase and to zinc in the oil phase. The aluminum bronze probe, which was in the immediate vicinity of the copper specimen mentioned above, also had a slight green color, but corrosion was insufficient to cause a resistance change during the 1800 hours of operation. A zinc probe installed in the oil phase after approximately 1000 hours of operation indicated corrosion, which is illustrated in Figure 17. It also should be noted that this oil contains an acid-type, liquid-phase rust inhibitor which is known to react with zinc.

5.6.1.3 Oil Return Line Protection. The vapor space portion of the steel oil-return line showed moderate rusting throughout the 2-foot length after 1800 hours of operation. However, during the shorter 150-hour screening tests with VSI oils, the oil-return line showed no corrosion. Use of the MS 2190-TEP (no VSI) allowed vapor-space corrosion in the lower 2-inch portion of the return line in 150 hours. These results seem to indicate that vapor-space corrosion of the oil-return line occurs at a significantly slower rate than that of the sump. This result could be expected in that vapor-space surfaces of oil-return lines are in closer proximity to the oil than some of the sump surfaces.

5.6.1.4 VSI Depletion. The progress of the VSI material depletion of Oil D was followed during this test by both the total acid number[6] of the oil and its interfacial tension, measured by the drop-weight method.[6] Both methods indicated the same general trend. This VSI material depletion (total acid number method) is shown in Figure 18. It can be seen that the complete depletion

of inhibitor and the failure of Oil D as indicated by vapor-space rusting correlate with respect to operating time.

5.6.2 Oil E. Oil E gave vapor-space protection for approximately 3160 hours. The first rust spot on the sump cover was observed after approximately 3100 hours of operation. The amount of vapor-space corrosion permitted by Oil E after 3160 hours as shown in Figure 19 is comparable to that permitted by Oil D after 1800 hours of operation.

In general, the results with Oil E are similar to those with Oil D. The liquid-phase zinc corrosion shown in Figure 17 indicates that Oil E (as well as Oil D) is not compatible with zinc. Also, the electric resistance-type corrosion probes do not indicate vapor-space corrosion to aluminum bronze with Oil E although, as with Oil D, these probes had a thin green coating. In contrast to results obtained with Oil D, the copper specimen in the oil remained bright for the entire 3160 hours of operation. Also, Oil E differed from Oil D in both oil-phase rust protection and sludge formation. The 48-hour turbine-oil specification rust test results (see Section 5.7) indicated that severe oil-phase rusting was possible with Oil E. Therefore, the vapor-space-corrosion apparatus was shutdown for inspection after 2000 hours of operation, although there were no signs of vapor-space corrosion. Both the sump bottom and oil-return line were free of rust at this time. At the conclusion of the 3160-hour test, the sump bottom was moderately rusted where water globules had settled, as shown in Figure 20. While it is possible that the VSI material in Oil E may have contributed to this oil phase rusting, this effect is not clear, since, as noted in Table 1 of Section 5.7 the 2190-TEP base oil used to prepare Oil E was borderline in this respect.

A small amount of sludge was observed on the sump bottom at the 2000-hour inspection. This amount was much less than that for Oil D after 1800 hours of operation. Also there was no additional sludge buildup between 2000 and 3160 hours of operation. These observations are confirmed by the fact that the gear-case nozzle strainer plugged only once during the 3160-hour operation with Oil E compared with the 100-to 200-hour interval between nozzle plugging with Oil D. As discussed in Section 5.7 the turbine oil specification oxidation tests and the vapor-space-corrosion apparatus rank the sludge forming tendencies of these oils in the same order.

The depletion of the VSI material in Oil E with respect to operating time is shown in Figure 18. It can be seen that Oil E completely depleted in a much shorter length of time than Oil D. However, Oil E provided vapor-space rust protection for a substantially longer period (3160 versus 1800 hours). This is a very interesting phenomenon in that no replenishment of the VSI material is necessary for this significant time period. This suggests a difference in behavior of the VSI material in Oil E than in Oil D. It appears that the VSI material of Oil E forms a rust resisting coating on the vapor-space surfaces.

5.7 Oil Quality Tests. Pertinent oil quality tests of Specification MIL-L-17331C run on vapor-space inhibited Oils D and E as well as the MS 2190-TEP base oil for Oil E (Code H) are presented in Appendix A. Oils D and E each departed from specification requirements as summarized in Table 1.

Table 1

Departure from Specification MIL-L-17331C Requirements

Test	Requirement	Oil D	Oil E	MS 2190-TEP Base Oil (Code H)
Neutralization No.[1], mg of KOH/gm	0.20 (max)	0.52	0.37	0.13
Oxidation,[2] Hours until Neut. No. reaches 2.0	1000 (min)	957	1000+	1000+
Mg Sludge after 1000 hours	---(3)	2014	925	771
Rust[4]	No Rust (48 hr)	Pass	Fail	Borderline

[1]ASTM Standard Method D-974-58T

[2]ASTM Standard Method D-943-54

[3]MIL-L-17331C has no sludge requirement, but MIL-L-17331D specifies 100 mg maximum

[4]ASTM Standard Method D-665-60, with addition of preliminary step of waterwashing of oil to remove readily water-soluble additives.

Oils D and E did not meet the neutralization number requirements. This, however, is considered a minor point if no other serious deficiencies are shown. Also, Oil D did not meet the oxidation requirements, but the difference is within the repeatability of the procedure. In this test, however, Oil D formed 2014 mg of sludge. While there is no sludge limitation in MIL-L-17331C (which was in existence when these oils were procured), the superseding specification MIL-L-17331D limits sludge formation to a maximum of 100 mg. In view of this limitation, the sludge formation properties of Oil D are particularly important. Oil E and the base oil (Code H) also gave significant amounts of sludge (925 and 771 mg, respectively). It is not possible to say whether the addition of VSI caused Oil E to produce more sludge than its base stock, Oil H, since the sludge increase is within the precision of this test. In contrast, three MS 2190-TEP oils (no VSI material) blended by the manufacturer of Oil D have been tested and all three were below the 100 mg limitation. As this manufacturer, at the time of procurement, represented Oil D as his current MS 2190-TEP formulation with the addition of the VSI material, the sludge-forming property possibly may be attributed to the VSI material. It will also be noted that Oil E failed to meet the rust test requirements of specification MIL-L-17331C. Since the base oil (Code H) for Oil E was borderline in this respect, the failure of Oil E in the rust test cannot definitely be placed on the VSI material used. However, these results indicate an area where more work is needed.

6.0 GENERAL DISCUSSION

6.1 Promising VSI Turbine Oils. The experimental results indicate that two VSI steam-turbine oils are promising with respect to affording vapor-space-corrosion protection. One of these oils, a commercial VSI steam-turbine Oil (Oil D), has a sludging problem which must be resolved before it can be recommended for a service trial in steam-turbine lubricating-oil systems. This oil is satisfactory with respect to the other physical and chemical properties tested. The supplier of this oil has been advised of the sludging problem and is working to correct it. A reformulated sample of this VSI oil has been received and testing begun. Concurrently, the supplier is evaluating this formulation in one of his tankers. The second promising oil (Oil E) is a laboratory formulation consisting of a commercial VSI additive material in MS 2190-TEP steam-turbine lubricating oil. This additive material is satisfactory as far as the testing has progressed. However, additional confirmatory testing of the VSI additive used in Oil E as discussed above is necessary in a MS 2190-TEP base oil which

meets the requirements of the current turbine oil specification MIL-L-17331D. Particularly, the sludging and liquid-phase rust protection properties must be confirmed.

6.2 Apparatus and Test Method. The vapor-space-corrosion apparatus was built to bridge the gap between laboratory-scale glassware apparatus and full-scale steam-turbine lubricating-oil systems with respect to vapor-space corrosion and VSI turbine oils. The experimental results show that the vapor-space-corrosion apparatus can simulate environmental atmospheres in steam-turbine lubricating-oil systems, and also expose possible material compatibility problems such as oil sludging and corrosion of non-ferrous metals. In addition, this apparatus can distinguish between VSI materials in lubricating oil. In this respect it is a valuable tool in the development of VSI materials for steam-turbine lubricating-oil applications. Furthermore, this application might be extended to include hydraulic fluids with which vapor-space corrosion may be a problem and to fluids used in flushing new or overhauled hydraulic and turbine lubricating oil systems.

8.0 CONCLUSIONS

From the experimental results obtained, it is concluded that:

- The use of VSI materials in operating steam turbine systems is feasible.

- Two VSI steam-turbine lubricating oils show promise for use in steam-turbine lubricating-oil systems but require further confirmatory testing of side effects.

- The vapor-space-corrosion apparatus permits testing under the environmental conditions encountered in steam-turbine lubricating-oil systems with respect to vapor-space corrosion.

- The apparatus can determine the relative effectiveness of vapor-space-corrosion protection offered by VSI materials in lubricating oils.

- The apparatus can expose possible material compatibility problems in VSI turbine oils.

9.0 FUTURE PLANS

The deficiencies of the two promising VSI oils, discussed above, must be corrected before a shipboard trial can be recommended. Specifically, the reformulation of commercial Oil D must be evaluated in the vapor-space-corrosion apparatus. In addition, its physical and chemical properties must be determined and compared with the requirements of Specification MIL-L-17331D. Any deviations from these requirements must be such that the functional characteristics of the lubricant in operation are not impaired. This work is currently under way, and upon successful completion, recommendations and guide lines for a shipboard trial will be proposed. Similarly, the promising laboratory VSI additive used in Oil E must be reevaluated using a MS 2190-TEP base oil which meets the requirements of Specification MIL-L-17331D, particularly for liquid-phase rust protection and for sludging in the oxidation test. This work will be undertaken upon completion of that on the commercial VSI oil.

Several tests will be performed for additional information on the VSI oils recommended for a shipboard trial. The effect of oil makeup additions on the vapor-space rust protection will be evaluated in the vapor-space-corrosion apparatus using available data of Fleet practice for makeup oil additions. Also, to be determined in this apparatus are the rust-arresting properties of these VSI oils for operating periods longer than those reported herein. The effect of oil cleaning (water removal) on the vapor-space inhibitor life also will be determined in centrifuge tests. Another important area for additional work is that of defining toxicity. As the effective concentration of the VSI materials in the oil is extremely low, it is unlikely that they would present a toxicity problem in surface vessels where there is adequate ventilation. However, use of these materials in closed machinery spaces, such as in submarines, may raise such a problem. Therefore, a toxicological study of the promising VSI turbine oils will be made. Also, as VSI material used in Oil E is patented, this situation will be discussed with the manufacturer when the application becomes more imminent.

The work outlined above is planned to provide the information necessary to specify the requirements and tests methods for VSI turbine oils. With the successful completion of the shipboard trials,,these requirements and test methods can be incorporated in a specification for VSI steam-turbine lubricating oils.

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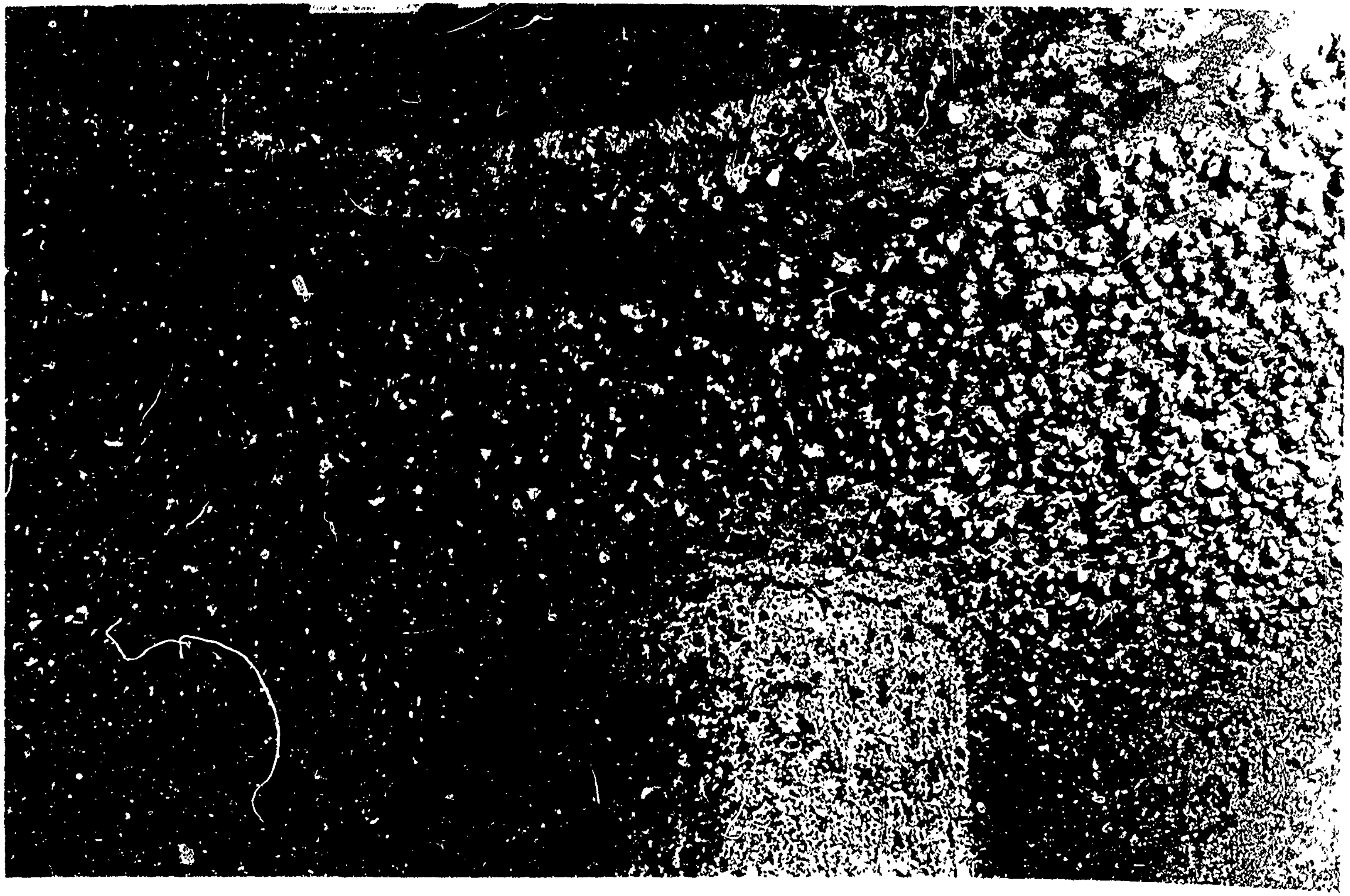

Figure 1 - Shipboard Lube Oil Sump Overhead

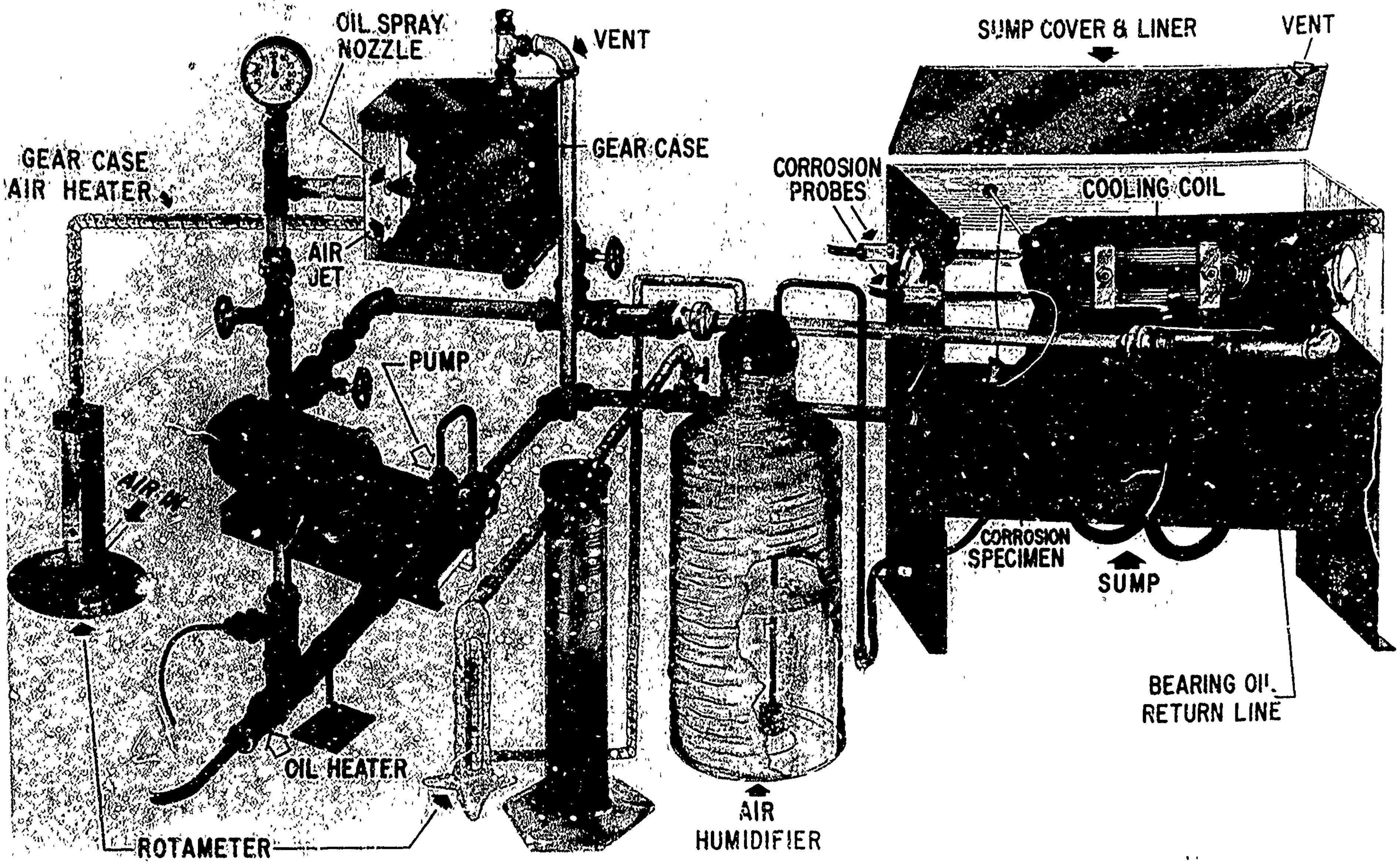

Figure 2 - Vapor-Space-Corrosion Apparatus

Figure 2 - Vapor-Space-Corrosion Apparatus

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Figure 3
Sump Cover, MS 2190-TEP, after 45 Hours of Operation

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Figure 4
Sump Cover, MS 2190-TEP After
150 Hours of Operation

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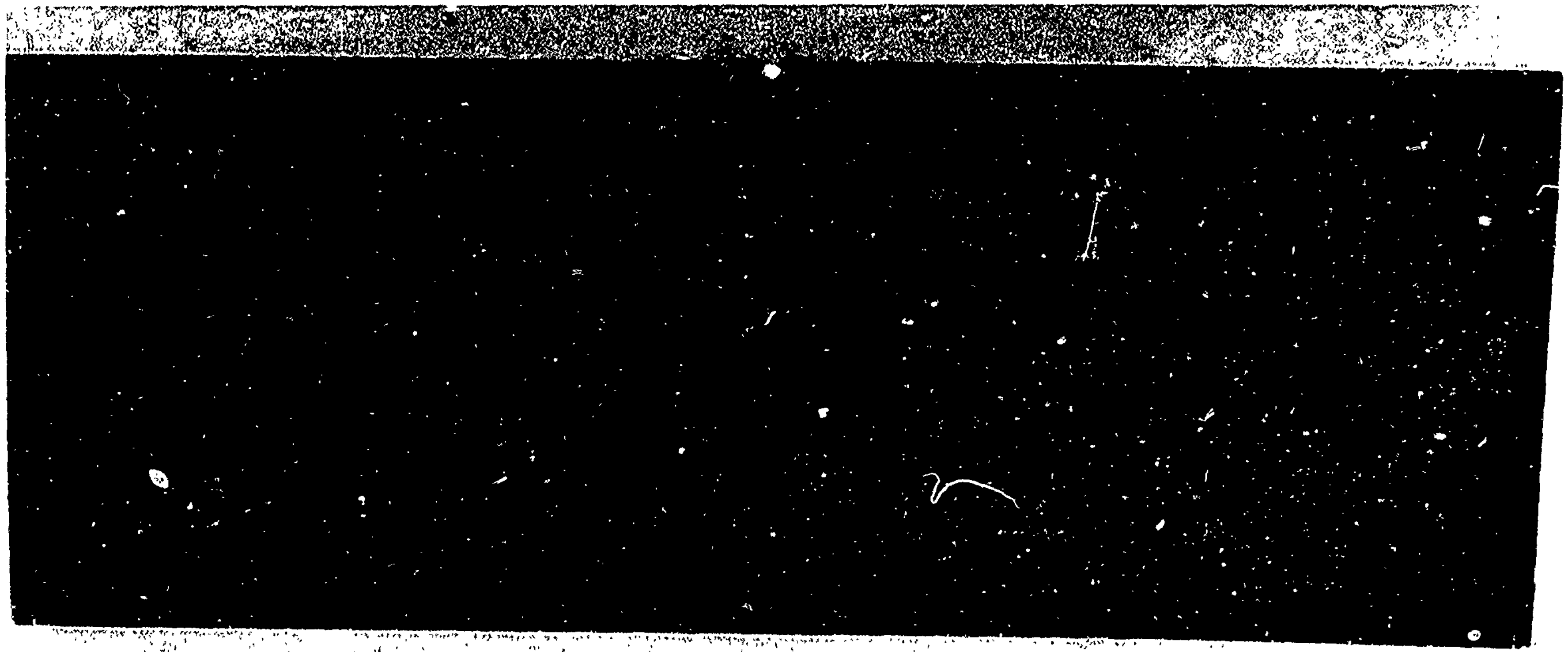

Figure 5
Sump Cover after 150 Hours
of Operation, Oil A

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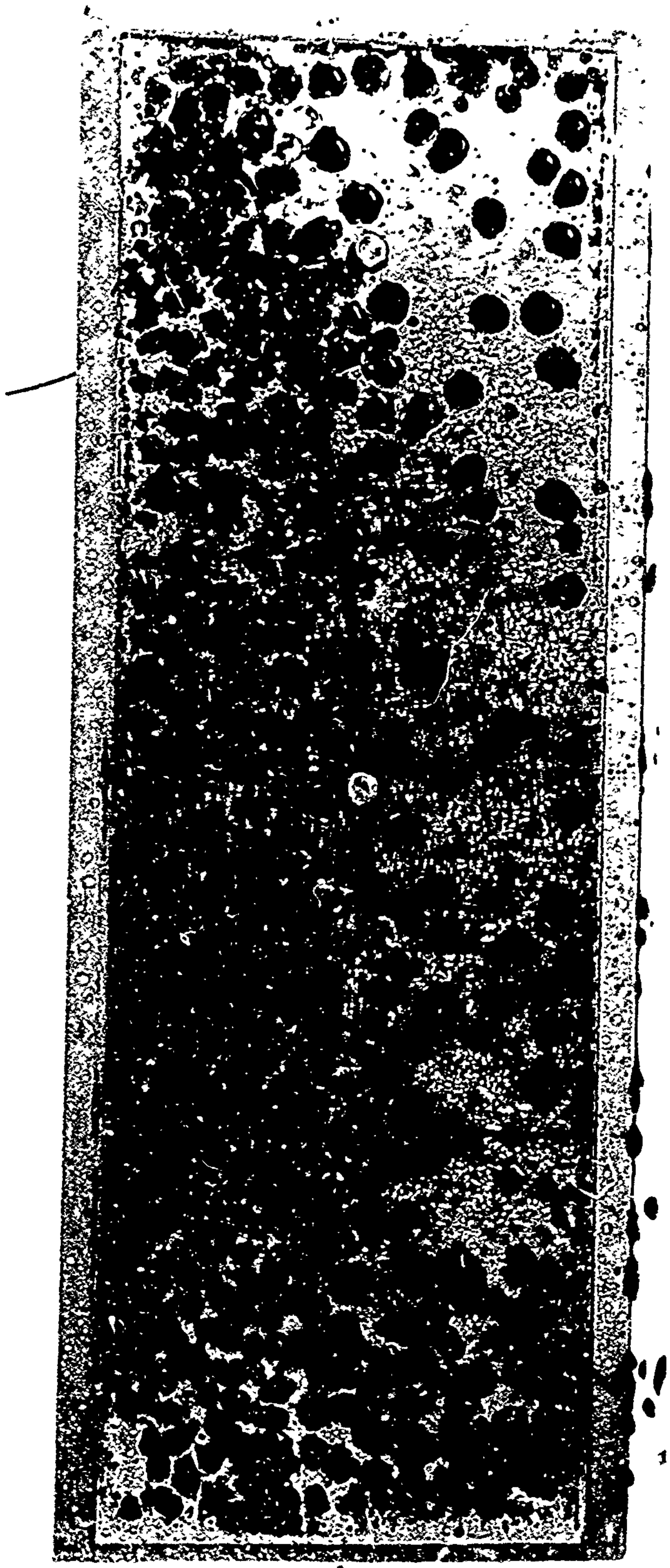

Figure 6
Sump Cover after 150 Hours
of Operation, Oil B

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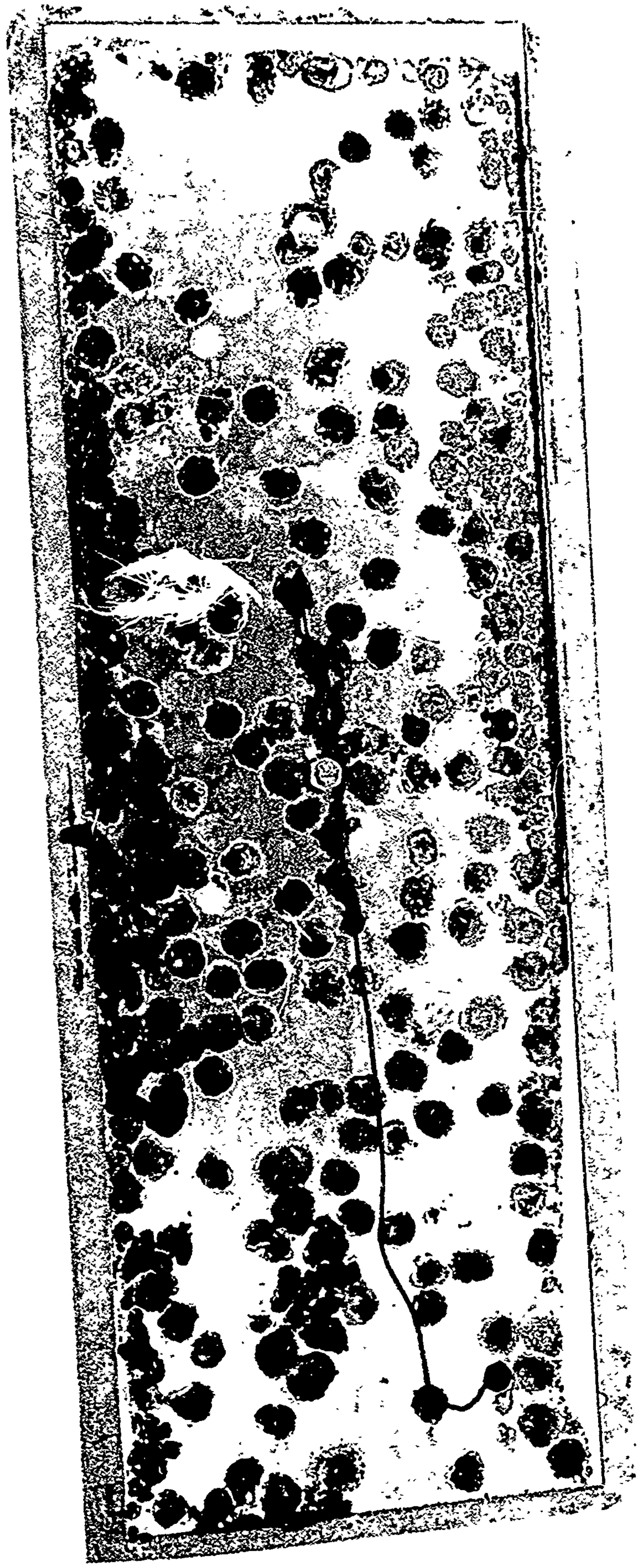

Figure 7
Sump Cover after 150 Hours
of Operation, Oil C

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Figure 8
Sump Cover and Liners after 150 Hours of Operation, Oil D

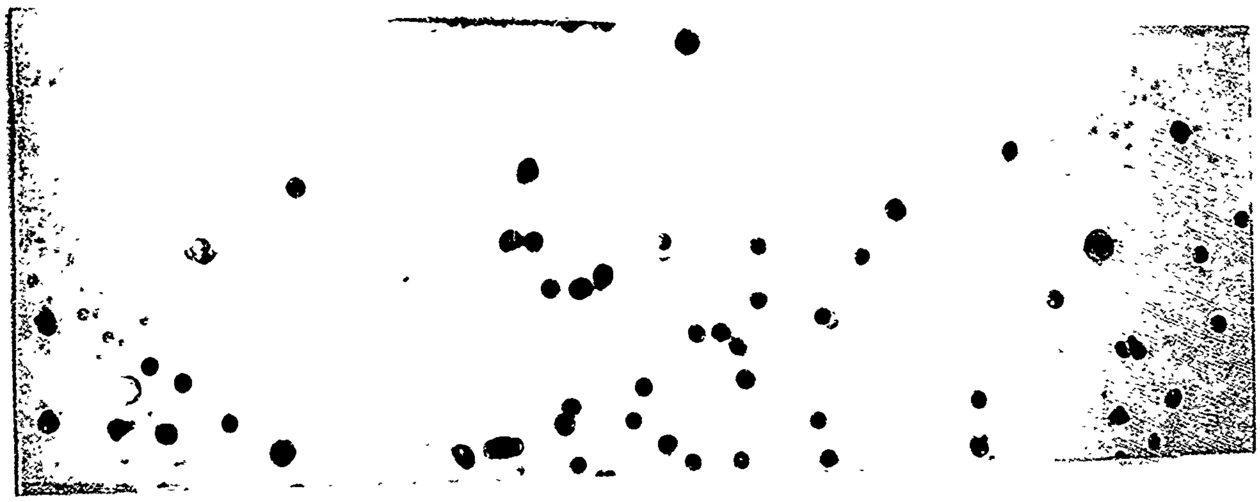

Figure 9 - Sump Cover after 150 Hours of Operation, Oil G

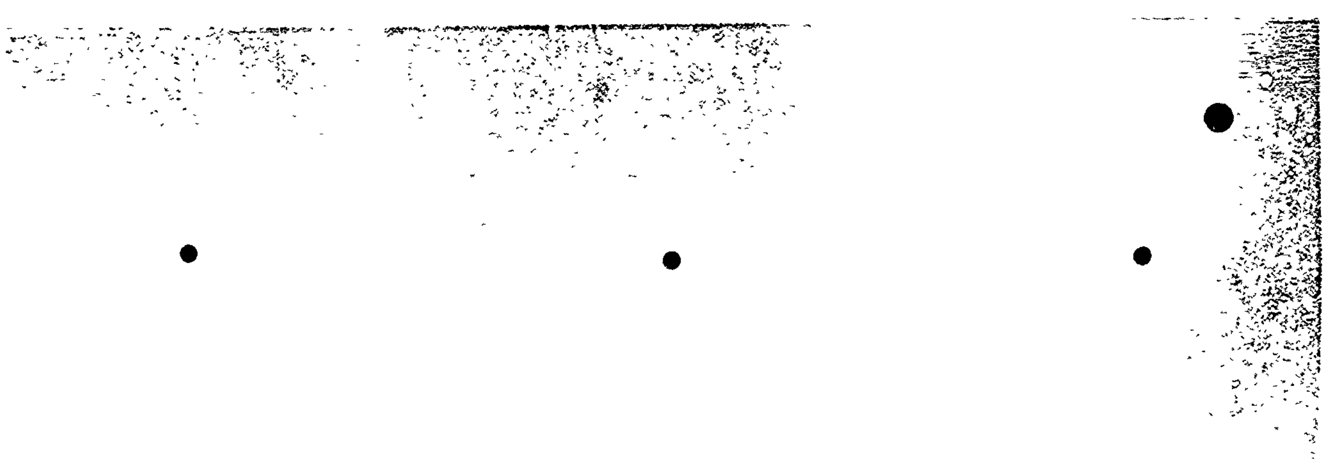

Figure 10 - Sump Cover New

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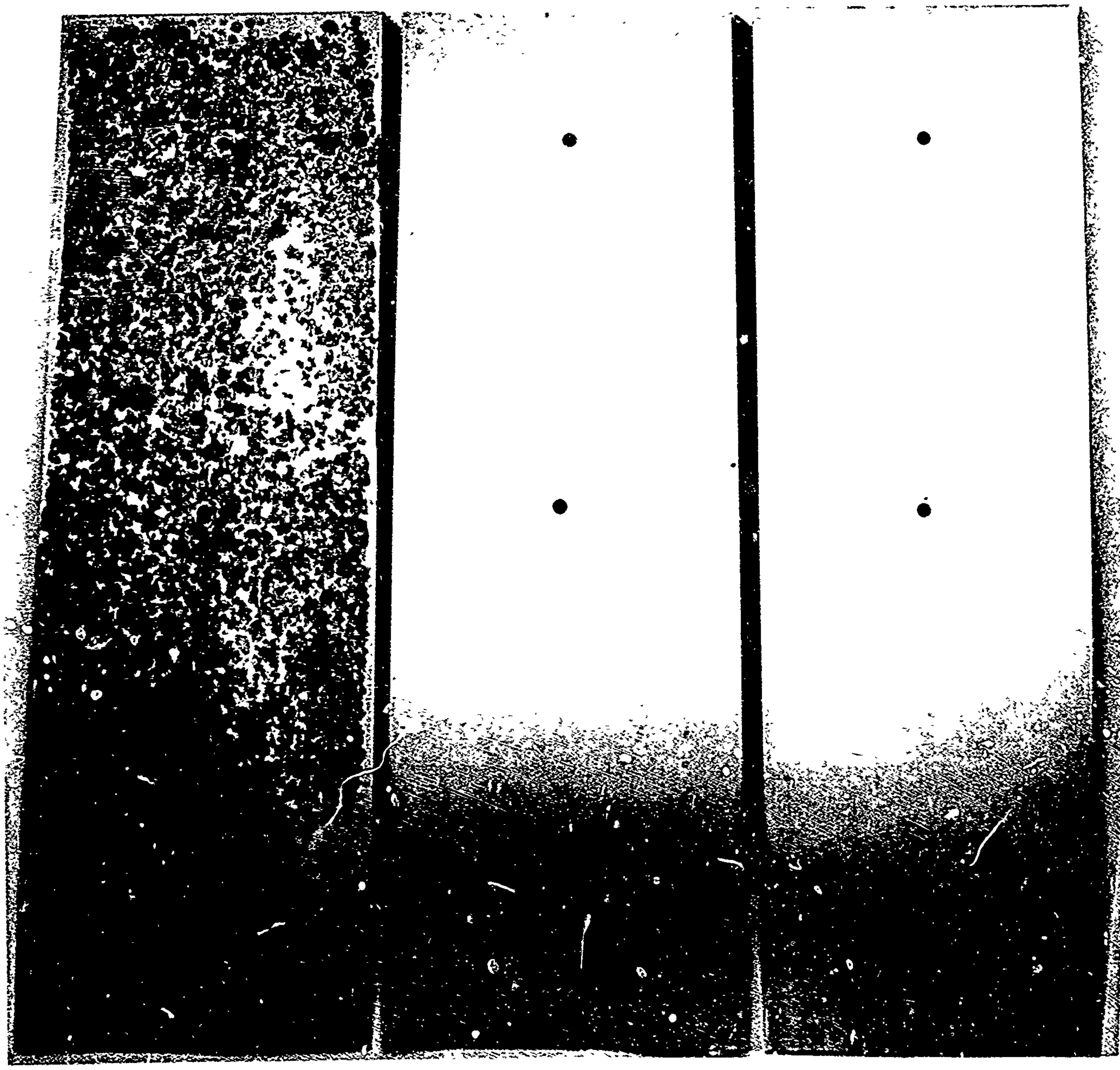

Oil H MS 2190-TEP 150 Hours	Oil D 350 Hours	Oil E 350 Hours

Figure 11
Sump Cover after 350-Hour Ambient Temperature Test

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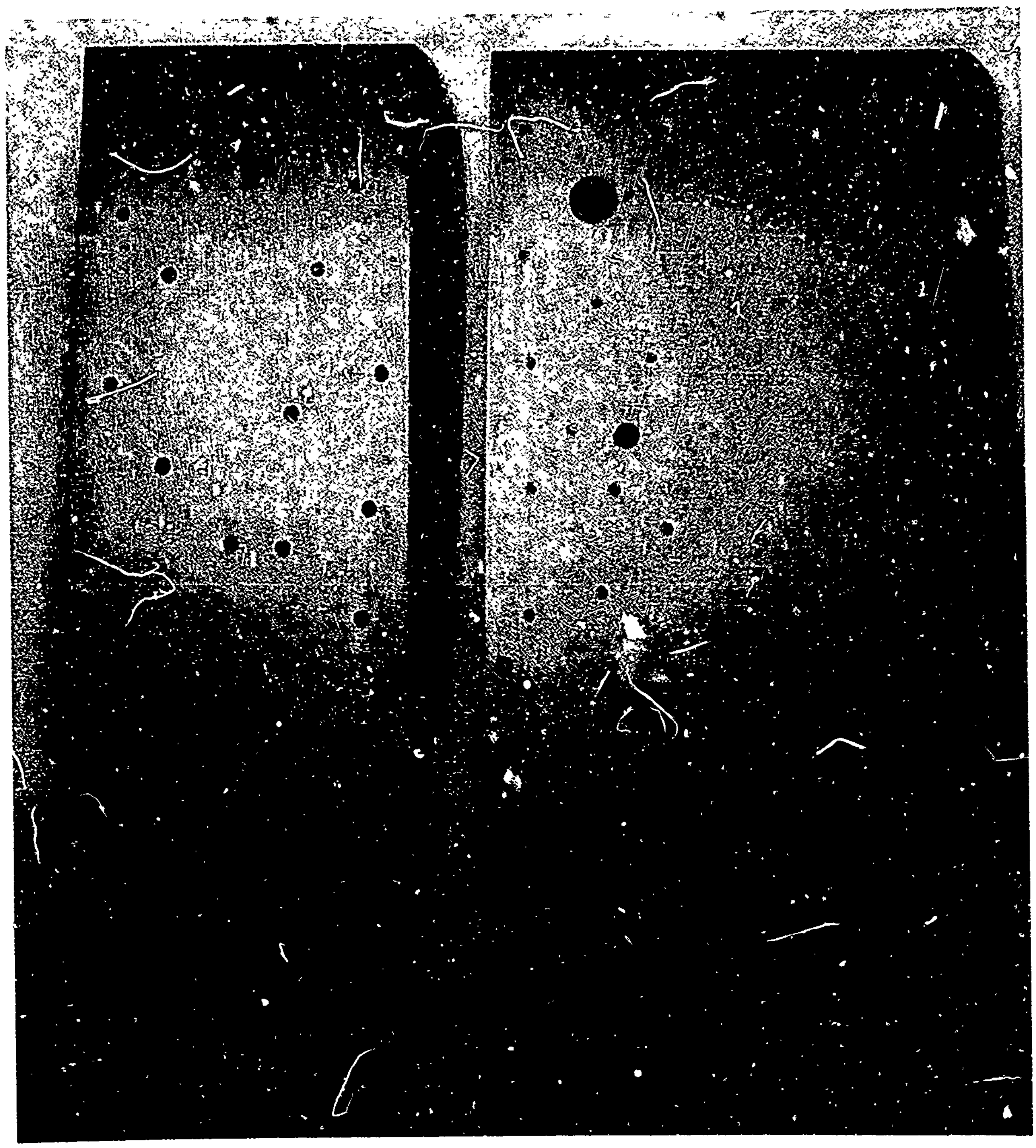

Figure 12
Partially Rusted Sump Liners

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Figure 14 - Partially Rusted Sump Cover after 150 Hours, Oil E

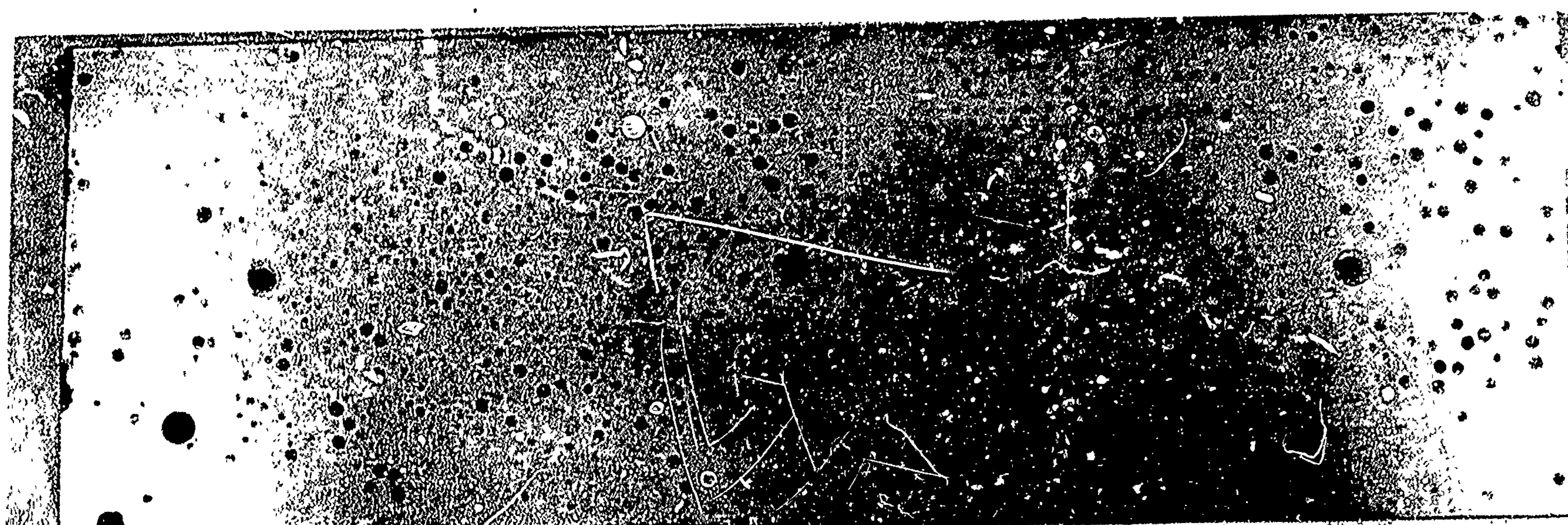

Figure 15 - Sump Cover after 1800 Hours of Operation, Oil D

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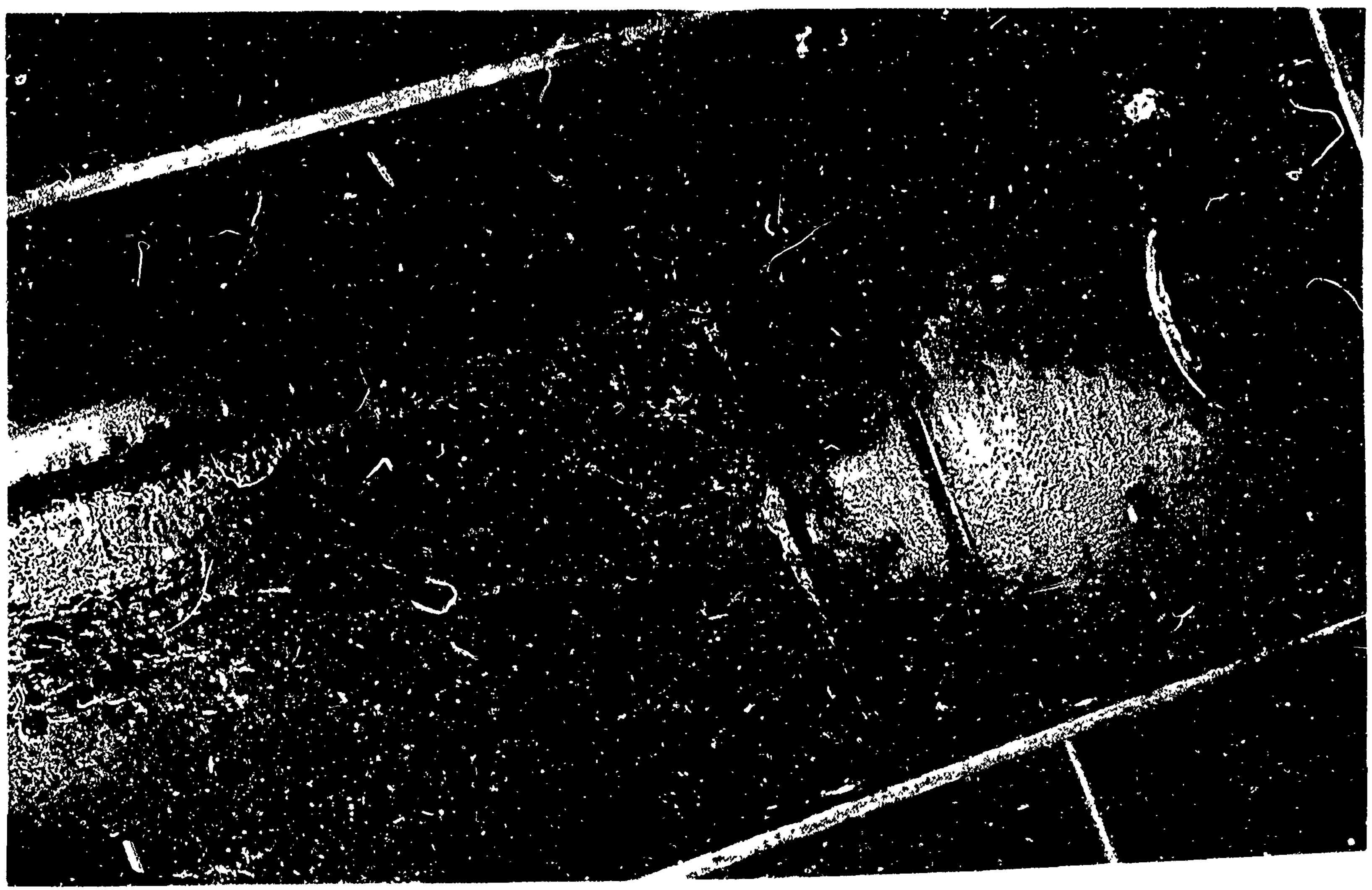

Figure 16 - Sludge from Oil D after 1800 Hours of Operation

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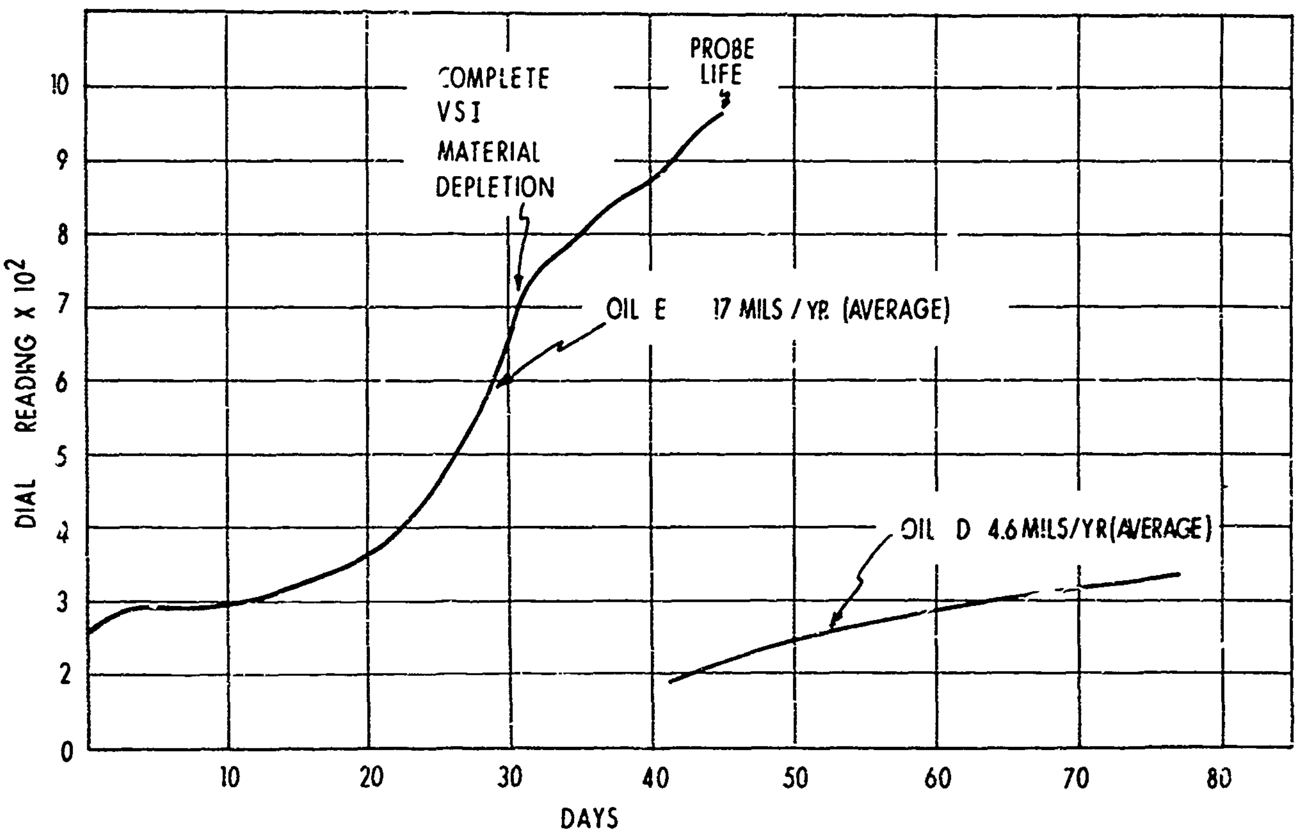

Figure 17
Oil Phase Zinc Corrosion

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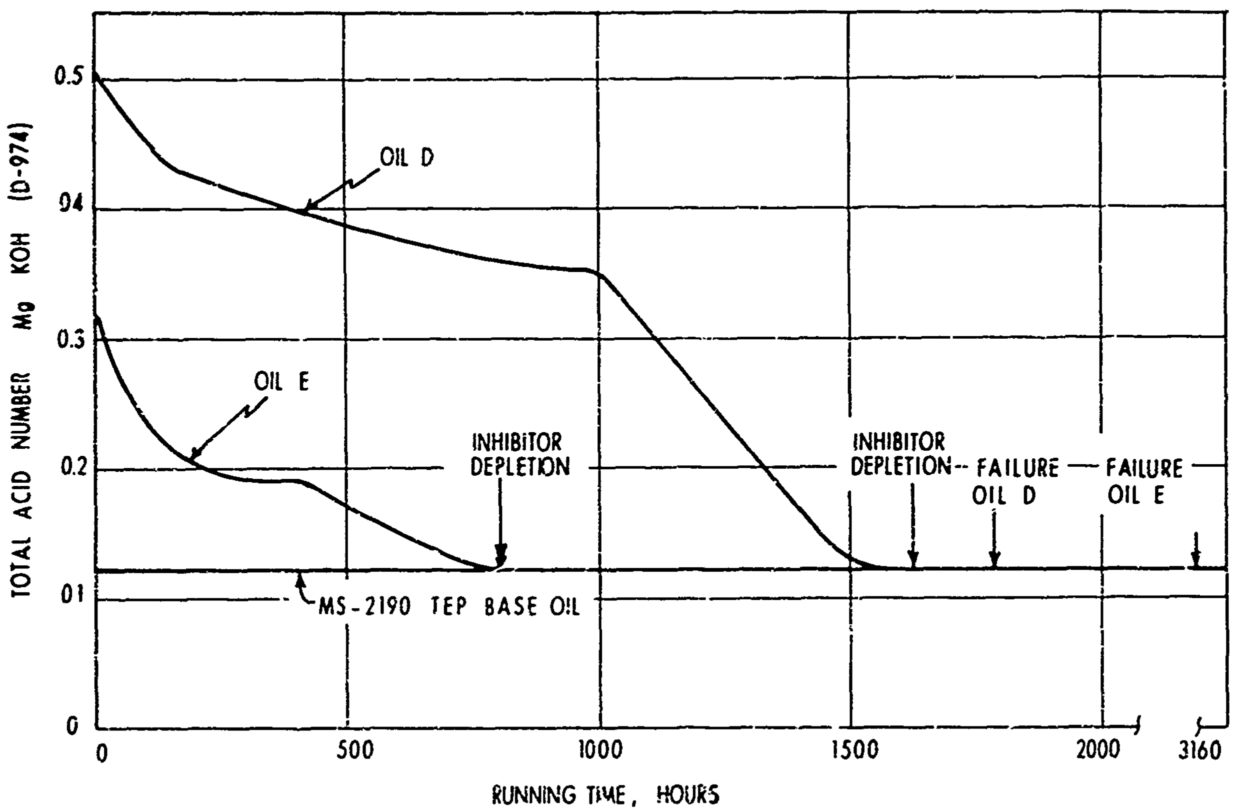

Figure 18
Vapor Space Inhibitor Depletion

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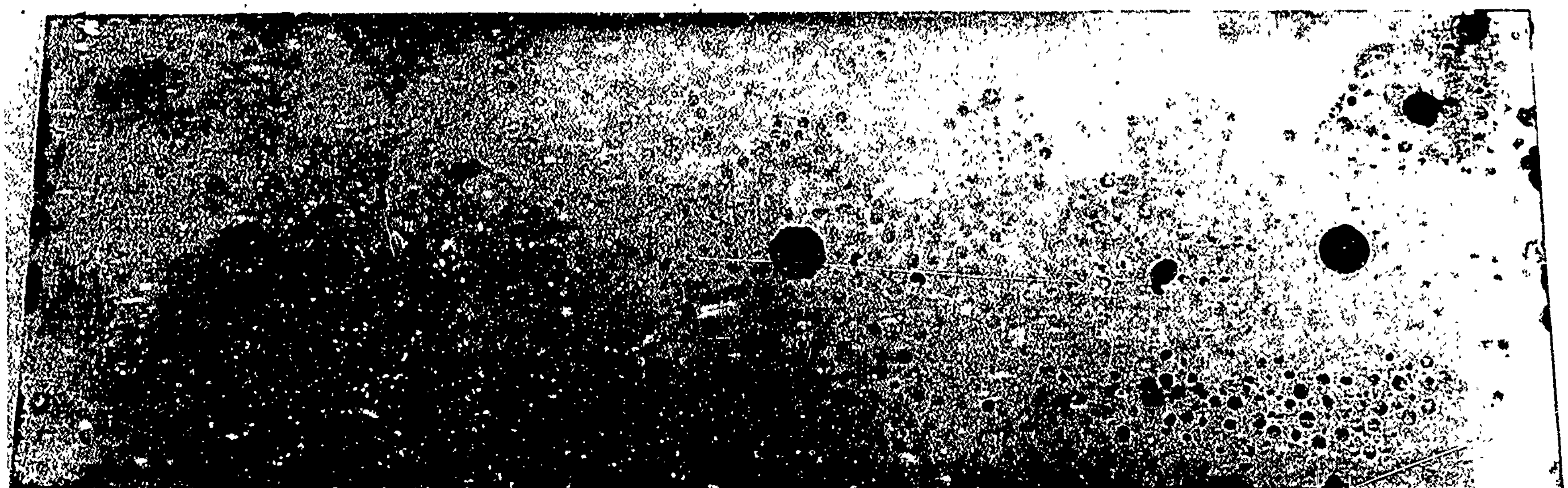

Figure 19
Sump Cover after 3160 Hours of Operation, Oil E

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Figure 20 - Sump Bottom after 3160 Hours of Operation, Oil E

Appendix A

Specification Tests for Steam-Turbine Lubricating Oils, MIL-L-17331C

Test	Oil D	Oil E	Base Oil for Oil E (MS 2190-TEP, Code H)
Flash Point, Open Cup, F	495	485	490
Viscosity			
SUS 100 F	401	418	416
SUS 130 F	184	194	191
SUS 210 F	57.6	58.6	58.5
Demulsification, min/sec	9:20	12:0	10:5
Neutrality	Neutral	Neutral	Neutral
Neutralization Number, mg KOH/gm	0.52	0.37	0.13
Corrosion, ASTM D665, 48 hrs, synthetic sea water,			
Water Washed 190 F	Pass	Fail (severe)	Borderline (Pass)
Not Water Washed	Pass	Fail	Pass
Oxidation, ASTM D943, Hours	957	1000	1000
Neutralization Number, mg KOH/gm	2.0	0.81	0.67
Sludge, mg	2014	925	771
Foam			
Sequence 1	Pass	Pass	Pass
Sequence 2	Pass	Pass	Pass
Sequence 3	Pass	Pass	Pass
Corrosion, Copper Strip, 212 F	1b	1a	1a
Load Carrying Capacity, Ryder ppi	2250	2194	2368
Four-Ball Wear, Scar Diameter, mm	0.30	0.34	0.31

Appendix B

Technical References

1 - Whyte, R. B., "Corrosion Tests with Vapour Space Inhibitors in Steam Turbine Oil," National Research Council of Canada, Mechanical Engineering Rept MP-29, Jul 1963

2 - Lurton, H. M., Rosalsky, I., and Seelback, C. L., "Vapor Space Inhibited Steam Turbine Oil," ASTM Preprint 85d, 1962

3 - ASME Standard No. 108, "Recommended Practice for the Design of Turbine Lubricating Systems," prepared by joint ASTM-ASME Committee on Turbine Lubrication, Sep 1955

4 - Vernon, W. H. F., "General Principles of Corrosion," Corrosion in Packaging, Packaging and Allied Trades Research Association - Institute of Packaging, London, Mar 1955

5 - Standard Method D-974-58T, "Neutralization Number by Color-Indication Titration," ASTM Standard Part 17, Jul 1963

6 - Proposed Tentative Method of Test for Interfacial Tension of Oil Against Water by the Drop-Weight Method, ASTM, Oct 1963

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Incorporating vapor-space-corrosion inhibitors in operating steam-turbine oils has been shown by laboratory experiments to be feasible. Two oils appear suitable for use in steam-turbine lubricating systems. Further confirmatory testing of side effects is underway.

(Author)

Security Classification Unclassified

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Rust, corrosion						
Rust inhibitors						
Vapor-space corrosion						
Rust inhibiting lubricants						
Steam turbine lubricants						

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